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MANUFACTURE OF TURBINE BLADE BLANKS

BY THE EXTRUSION METHOD

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INTRODUCTION

At turbine plants of the Soviet Union, turbine blades of constant-length cross-section and greater stem cross-section area than working cross-section area are usually manufactured by the following methods:

1. By machining out a bar, the length of which is equal to the length of the blade (and stem), with transverse dimensions corresponding to the cross-section dimensions of the working portions of the blade and stem.

2. Machining by cutting from drop forged blanks.

3. By the so-called "integral" rolling with subsequent machining by cutting.

The first method (most universal) is characterized by the utilization of a considerable quantity of metal-cutting equipment and comparatively low efficiency, and results in considerable waste of alloy steels, since wastage in chips for certain blade configurations reaches 200-300 percent of the weight of a finished blade.

The second method is more economical and efficient. However, allowances for machining in drop hammer forging are usually quite large, with small durability of stampings and their high relative cost. Besides, the surface of stamped products is frequently of low quality due to impressed slag. The use of a subsequent cold calking process has not yet received widespread acceptance by turbine plants in view of its unprofitableness in the small scale nature of turbine production; therefore, drop forging of turbine blade blanks with subsequent machining by cutting is limited only to blades of large dimensions (more than 250-300 millimeters long).

Integral rolling is an advanced process. However, the rolling of short blades on cylindrical rollers entails the labor-consuming process of making a special tool. Rapidly developing domestic turbine-building requires the utilization of more economical and efficient technological processes of turbine blade manufacture. Such a process is the hereinbelow described new technological process of manufacture of blade blanks having a constant length working cross-section, which permits the reduction of metal losses, and speeds up the mechanical machining of blades. The process involves the direct extrusion of blade blanks with a minimum allowance for mechanical machining. The stem of the blade of required shape can be made out of the remaining metal.

Blanks are extruded on standard forge-pressing equipment (friction, crank, or hydraulic presses, horizontal forging machines). The die is of simple design and can be made on the usual metal-cutting machine tools.

1. MANUFACTURED PRODUCTS

The technological process of extrusion was developed and tested in application to four types of blades having constant-length working portion profiles. The first type are blades with stems within the working cross-section profile (Figure 1, a, b, c).

Figure 1. Blades with stems within the working cross-section profile. Type one.

Types two and three are blades with stems of complex shape (Figure 2).

Type 4 are blades with rectangular shaped stems (Figure 3). Blades of the first type, with profiles of 3 different dimensions were made of brass, similar in chemical composition and mechanical characteristics to Grade LS 59-1.

Figure 2. Blades with stems of complex shape. Types 2 and 3. On Figure 4 there are shown blade blanks of the first type made by extrusion. (The process of extrusion permits the production of very long blanks. The length of the depicted blanks was limited, during the experiment, by power of the equipment).

In making the blades of the second, third and fourth types the following grades of carbon, stainless and heat-resistant steels were used: 50, u7, u8, 12Kh14A, 18Kh14A, EI-69 and Armco iron. In Figure 5 there are shown extruded blade blanks of the fourth type.

Figure 3. Blade with the rectangular shaped stem. Type four.

Figure 4. Shapes of blade blanks of the first type.

Figure 5. Shapes of blade blanks of the fourth type.

2. EXTRUSION DIES

The basic requirements of extrusion die design are simplicity of manufacture, ensuring of minimum tolerances and allowances for the size of the product, elimination of the effect of die chamfer on the precision of the manufactured product, and the possibility of replacement of the most rapidly wearing parts, such as the die matrices.

For the purposes of maximum universality and simplicity of production of blade blanks of the first and fourth types, layer extrusion dies were designed and manufactured which permit the performance of extrusion on the usual forging presses, friction, hydraulic or mechanical.

Figure 6 is shown the general view of the layer-type extrusion dies for a blade of type 4. Into the housing (1) there are pressed in dies 2 and 3 to effect the intimate contact of the die surfaces, constant restriction of working recesses and precise guiding of the punch. Die 3 has only one projection which forms the groove of the working portion of the blade. Die 2 has a groove corresponding in size and shape (considering minimum allowances) to the dimensions of the stem and back portion of the blade.

Figure 6. General view of the layer extrusion die for blades of type 4: 1-Housing. 2,3-Dies. 4-punch.

Figure 7. General view of extrusion die for blades of

types 3 and 4. 1-Punch; 2-Upper die; 3-Lower die; 4-intermediate insert; 5-Housing; 6-Blade blank.

For blades of types 2 and 3 there has been manufactured and tested a highly efficient extrusion die (Figure 7). (The extrusion die is efficient in the case of exact fit of the sliding surfaces). The punch (1) is fixed in the extruding slide and has a projection for pushing the blade blank out of the extrusion die on the return stroke of the press. Productivity of the extrusion die is determined by the number of press strokes corrected by the coefficient of utilization, which depends on the shop-space arrangement.

Great attention in the design of the extrusion die should be devoted to the choice of the die plate material and its shape. Correctly chosen die plate steel and proper thermal treatment ensure the successful extrusion of a large number of blades. The same considerations are equally applicable to the punch material, although decrease in its size, due to the wearing out of its pressure portion, does not affect the cross-sectional dimensions of the working profile of the blade, and only results in the increase of the size of the chamfer and increased extrusion stress. The die plate material should be wear-resistant and capable of withstanding high variable temperatures and pressures during the extrusion process. Quality of the working surfaces of the die plates and their hardness should not change appreciably with time. The surface of the die plate and its interior should not exhibit any symptoms of cracks due to thermal treatment. For materials of die plates used in hot extrusion of complicated profiles, according to certain technical sources, the following steels listed in Table 1 are recommended.

TABLE 1

Steel Compositions of Tools for Hot Extrusion of Complex Profiles

Country	Chemical composition									
	C	Si	Mn	Cr	Ni	W	V	Cu	P	S
USSR	0.30		0.20	2.2		7.5	0.20			
	0.40	0.35	0.40	2.7	0.3	9.0	0.50	-	0.03	0.03
GERMANY	0.22									
	0.30	0.30	0.24	2.05		11.7	0.25	0.3	0.03	0.03
US	0.32	0.20	0.10	3.00		9.75	0.35		0.03	0.03
	0.42	0.40	0.30	3.50		10.75	0.60			
	0.42	0.20	0.20	3.25		13.50	0.60		0.025	0.025
	0.42	0.35	0.40	3.75		15.00	0.75			

Experience in hot extrusion of brass blade blanks (first type) has confirmed the possibility of utilizing extrusion dies with matrices made of steel, Grade 7Kh3, heat treated for a hardness of R_C= 44+49.

Determination of the optimum steel composition is not the subject of this work, and requires lengthy mass experiments.

However, on the basis of a considerable number of experiments, it has been established the most durable are extrusion dies made of 3 KhV8 steel with nitrided grooves.

3. PROFILE OF THE DIE PLATE GROOVES

The shape, precision and quality of manufacture of the die plate grooves have a decisive effect on the course of the extrusion process, as well as upon the dimension and quality of the finished product. Cross-section dimensions of extruded blades correspond with a high degree of accuracy to the cross-section profile dimensions. The magnitude of possible deviations usually does not exceed 0.05-0.1 millimeters (in the direction perpendicular to the axis of the blade) and depends on shrinkage during cooling and elastic extrusion die deformations (in the transverse direction)

Figure 8. Profile of the working portion of the blade.

Figure 9. Profile of the working portion of the blade blank.

Since these two factors act in opposite directions (elastic extrusion die deformation leads to the increase in the transverse cross-section, while cooling shrinkage results in the cross-sectional decrease), their total effect ensures the high precision of the process. The length of the die plate grooves has a material effect upon the amount of work done by the extrusion press during the extruding, and also upon the shape of the finished product. The amount of work increases with the increase in the length of the die plate. However, for a short groove the profile of the blade, upon emergence from the groove, suffers considerable twisting, and the extruded blade must undergo the additional operation of straightening.

To avoid this, it is necessary that the length of the die plate be no less than the length of the working portion of the finished blade. The nature of the groove profile should also satisfy certain special conditions. The majority of the blade profile has sharp edges and a comparatively thick middle portion -- the back (Figure 8). This determines the unequal speed of flow of material into the profile of the die plate, and consequently results in the presence of considerable internal stresses in the metal.

Faster cooling of the thin edges, and, consequently, the decrease in the plasticity of the metal, may cause rupture of the edges. To forestall these phenomena it is necessary to provide for pockets within those die grooves which form the thin edges, which result in some bulging of the profile. The presence of such bulgings (Figure 9) results in the necessity of supplemental mechanical machining -- removal of the bulge by a cutter (not a shaper) -- but fully prevents rejects through rupture of blade edges.

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4. TEMPERATURE REGIME FOR THE EXTRUSION PROCESS

Experiments conducted in extrusion of blades from different grades of steel point to the necessity of heating the blanks up to temperatures close to the upper limit of the forging range.

Extrusion at temperatures close to the lower limit of the forging range results in a large percentage of rejects due to ruptures of the thin blade edges, and, besides, leads to faster wearing out of the die plates, in view of the increased deformation resistance of the metal. In connection with this, and also in order to decrease slag formation during the heating in flame furnaces, heating should be of forced nature, maintaining the furnace temperature 50-100 degrees higher than is usual in heating for stamping purposes.

From this standpoint the most progressive is the utilization of electric induction heating, since experimental data confirms the possibility of heating of highly alloyed steels without burning and overheating to temperatures of 50-80 degrees Centigrade in excess of the upper level of the forging range for these steels.

The temperature of heating of the extrusion die has a decisive effect on the production of usable products. The optimum temperature of heating of the extrusion die is in the 250-300 degree Centigrade range.

5. SLAG, AND ITS ROLE IN THE EXTRUSION PROCESS

Slag, which emerges on the blank during furnace heating and which enters together with the metal of the blank into the working recesses of the extrusion die, complicates, during extrusion, the shaping of the blade, increases the deformation force and constitutes a reason for rejects and fast wearing of the working parts of the extrusion die. Entrance of slag into the working recesses of the extrusion die causes scoring and scratching of the product surface, and metallic influxes on the surfaces of the working recesses of the die, which in turn causes surface spoilage of the product during further extrusion.

In this connection, during the treating in flame furnaces, it is necessary to protect the blanks from slag formation (for example, heating in inert atmosphere or muffle).

Best results are obtained from electric induction heating; with correct choice of the inductor and power of the heating installation, almost no slag is formed.

6. PROCESS OF EXTRUSION

Manufacture of a usable product is possible only in a continuous process of deformation. Any interruption of the continuity of the extrusion process of the heated blank, such as, for example, removal of the external loading, and its instantaneously repeated application to the deformed blank, leads inevitably to the breaks in the texture continuity of the product.

In view of the considerable stress being undergone by the deforming blank, these breaks appear on the outward surfaces of the thin portions of the product and always are in conspicuous open view. Formation of breaks was observed in all cases of interrupted deformation of products made of brass, Armco iron, carbon, stainless and heat-resistant steels. With continuous deformation, and in the conditions of normal temperature range, as well as with correct design of extrusion dies, extrusion of the above-mentioned metals always resulted in usable products. It is necessary to point out that extrusion of blades out of stainless and heat resistant steels, although it required the application of great forces and the utilization of high quality extrusion die, proceeded more favorably than the extrusion of blades of low carbon steels. In the conditions of stresses attending the extrusion process, the heat resistant and stainless steels (of tested grades) are less susceptible to scoring, breaks of thin cross-sections and are distinguished for the smooth surfaced finished products.

7. LUBRICATION

Lubricating the working parts of the extrusion die eases considerably the flow of metal during extrusion, ensures removal from the die of the finished product and almost fully prevents scoring of the working parts of the die. Besides, it is necessary to mention the considerable lowering of the pressure developed by the die when a judicially chosen lubricant is used.

In extrusion of steel blade blanks, best results are

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obtained from lubricating mixtures particularly using the mixture of graphite and machine oil (cylinder oil 6) with 50 percent of graphite by volume. However, utilization of graphite lubrication in hot extrusion of brass profiles, the surfaces of which are only polished after extrusion, is not recommended. Employment of graphite lubrication leads, in a number of cases, to the depositing of graphite on the surface of the profile. For lubrication it is possible to use, for example, machine oil.

8. SPEED AND FORCE REGIMES FOR EXTRUSION

Extrusion of steel blades of the second and third types was conducted on an off-center press with pressure of 100 tons at 75 strokes per minute. The magnitude of the press stroke was 100 millimeters. The speed of the punch movement during the extrusion of blades varied from 0.3 meters per second (at the time of making contact with the blank) to zero (at the extreme downward position of the slide). Determination of the pressing force by means of an angular dynamometer gives reason to believe that, for extruding steel blades of stainless steels, the necessary force relative to the cross section area of the stem is 15-30 ton per square centimeter. For brass blades of the first type this force relative to the cross section area of remaining metal is 10-15 tons per square centimeter. It should be taken into account that equipment selected should have sufficient power for the entire deforming job and removal of the blank on the return stroke of the slide.

Extruding brass blades was conducted on friction and off-center presses with pressures of 60-100 tons with the corresponding number of strokes or 18-75 per minute. The force necessary to remove a blade of the fourth type from the extrusion die is 15-17 tons. Extrusion blades of the fourth type was conducted on a 750 ton hydraulic press in view of the lack of a more suitable one. (Computed stress in the extrusion of blades of the fourth type is about 400 tons).

9. QUALITY OF MANUFACTURED PRODUCTS

No defects, such as breaks in the texture of material, voids, or pinching of material in the transitional cross sections were found during etching tests on longitudinal sections of blades of all of the four types. Macrostructure of all the longitudinal sections indicates the extension of crystals in the direction of deformation. Figure 10 is a photograph of the structure of a blade of the fourth type.

Figure 10. Microstructure of the material of a pressed blade blank of the fourth type. Longitudinal section.

Such structure has great advantages over the structure of a blade milled from a bar of metal. In a milled blade (of second, third and fourth types), the metallic grain at the point of transition of the working portion of the blade into the stem portion is discontinuous, which lead to a lowering of the fatigue resistance of the blade. In an extruded blade, the metallic grain accurately follows the shape of the product. This gives reason to believe that the design, durability and fatigue resistance of extruded blades are higher than those of milled blades.

10. EFFECTIVENESS OF THE EXTRUSION PROCESS

Comparative data on the expenditure of metal per one completely finished blade by machining a bar of metal and by the process of extrusion, with subsequent mechanical finishing, are given in Table 2.

[See next page for Table 2]

Savings of metal can be increased when several blades are made out of one blank, since the weight of metal left over from extrusion is pro-rated over the entire number of finished blades instead of applying to one blade as in the above example.

Data of the above table indicates that in milling a blade from a metallic bar, the loss of metal through chips is equal to 252-412 percent of the weight of the finished product, while in extrusion, the loss through chips comprises only 24-102 percent. It becomes evident then that employment of the extrusion method in mass production results in a considerable economy of metal. For various designs of turbine blades, this saving will be different; for the shapes of blades described in this article, this saving will amount to 47-67 percent of the currently used milling blanks.

TABLE 2

Blade Type	Mechanical Machinery: Weight of Blank in g	Mechanical Machinery: Weight of finished product in g	Mechanical Machinery: Loss of Metal through chips as a percent of the Finished Product Weight	Extrusion process: Weight of Blank in g	Extrusion process: Weight of finished product in g	Extrusion process: Loss of metal through chips as a percent of the weight of Finished Product	Savings of Metal as Compared with the Mechanical Machining Method: Saving in the weight of blank	Savings of Metal as Compared with the Mechanical Machining Method: Saving in percent of the weight of the blank
1a	133	26	412	44	26	69.3	89	67 2
16	133	27	392	46.6	27	72	86.4	65
1b	143	32	347	53	32	65.6	90	63
2	206	51.5	304	66.5	51.5	29.2	139.5	67
3	218	69	252	86	69	24.6	132	60
4	1100	290	280	585	290	102	515	47

Productivity of the extrusion method of blade manufacture is very high. For example, extrusion of the second and third type blades was conducted on a 100 ton press with 75 strokes per minute. If we take even the coefficient of effective press strokes as 5 percent using only 4 strokes per minute, which is entirely possible with certain mechanization of blank feed, and on the condition that the work is not hindered by [slow] heating, then the per shift productivity of such a press will be expressed by the figure 1,920, which is many times greater than the productivity of a milling machine engaged in rough machining of blade blanks out of metallic bars.

Productivity of labor in extrusion of blades on a hydraulic press utilizing the above-mentioned type of the layer extrusion die (Figure 6) will be considerably lower and can be realistically expressed as 100-120 blanks per shift.

However, utilization of an extrusion die of different design (for example, one with an ejector for removing the blank from the die on the return stroke of the press, or the wedge type with dies that open on the return stroke of the press), appears highly practical to utilize horizontal forging machines for the extrusion process.

The adoption by industry of the new process of manufacturing of blade blanks by means of the extrusion method would greatly increase productivity and release a large number of metal-cutting machine tools.

11. TYPES OF REJECTS

Types of rejects observed in mass extrusion of blades are as follows:

(a) Damage to the external surfaces of the finished product as exemplified in scoring and scratches. The reason for poor surface finish was the presence of slag.

In case of minute scratches and scorings, a usable product can be obtained from the blank upon subsequent mechanical machining. Scorings and scratches caused by slag entering the working chamber of the extrusion die, do not cause discontinuities in metal texture inside of the blade proper. Measures for the prevention of rejects are the thorough elimination from blanks of slag and blowing of compressed air through the working chamber of the die. Best results are obtained by using electric induction heating, which results in almost oxide-free blanks.

(b) Ruptures of sharp blade edges, the reason for which is the low temperature of heating of the blank or the low heating temperature of the die. Measures for the prevention of this type of reject are heating of the die and increasing of the temperature of extrusion.

(c) Scoring of the product or the appearance on it of metallic bulges during slagless extrusion caused by the scoring of the extrusion die. Internal trimming of the die prevents this type of reject.

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12. CONCLUSIONS

Practical experience with manufacturing the four types of blades permits one to draw the following conclusions:

Blade extruding can be conducted by means of the usual friction, crank and hydraulic presses having adequate power, blank capacity, and magnitude of working stroke. Utilization of the horizontal forging machines is extremely apropos. Extrusion can be conducted successfully by means of disengaging or non-disengaging closed extrusion dies. In the latter instance the die should have an ejector or an extractor.

The groove length of the dies should be no less than the length of the working portion of the blade. In this case the product comes out absolutely straight and does not require further straightening.

Introduction of technological bulges on the thin blade edges facilitates the extrusion process and increases the temperature range of extrusion. The heating temperature of extruded blanks should be close to the upper limit of the forging range.

Temperature of heating of the extrusion die should not be less than 250-300 degrees Centigrade.

In conditions of normal temperature regimes, continuous deformation of metal by extrusion ensures the production of a usable product. The process of deforming of hot blanks proceeds even more successfully with lubrication of the working chambers of the die.

Extrusion of steel blades should only be conducted with graphite lubrication of the working chambers of the die. Production of usable blades in large quantities through pressing is possible if there is a total absence of slag on the hot blanks. If this is the case, complete identicalness of the manufactured objects and freedom from rejects is assured.

The most effective method of blank heating should be regarded as that which completely excludes the possibility of slag formation upon the blank. One of these methods can be the electric induction heating method. Production of large quantities of blades identical in size and weight is possible only when working with blanks of precise profiles and weights.

Extrusion of blades from stainless and heat resistant steels proceeds more favorably than the extrusion of carbon steels. 12Kh14A, 18Kh14A and EI-69 grades of steel are less subject to scoring under the stress of the extrusion process, and are distinguished by the smooth surface of their finished product.

The technology of blade manufacture by the extrusion method is more economical and efficient than the commonly accepted technology of blade manufacture from metal bars. Introduction of the extrusion process results in a great economy of money, time, and metal.